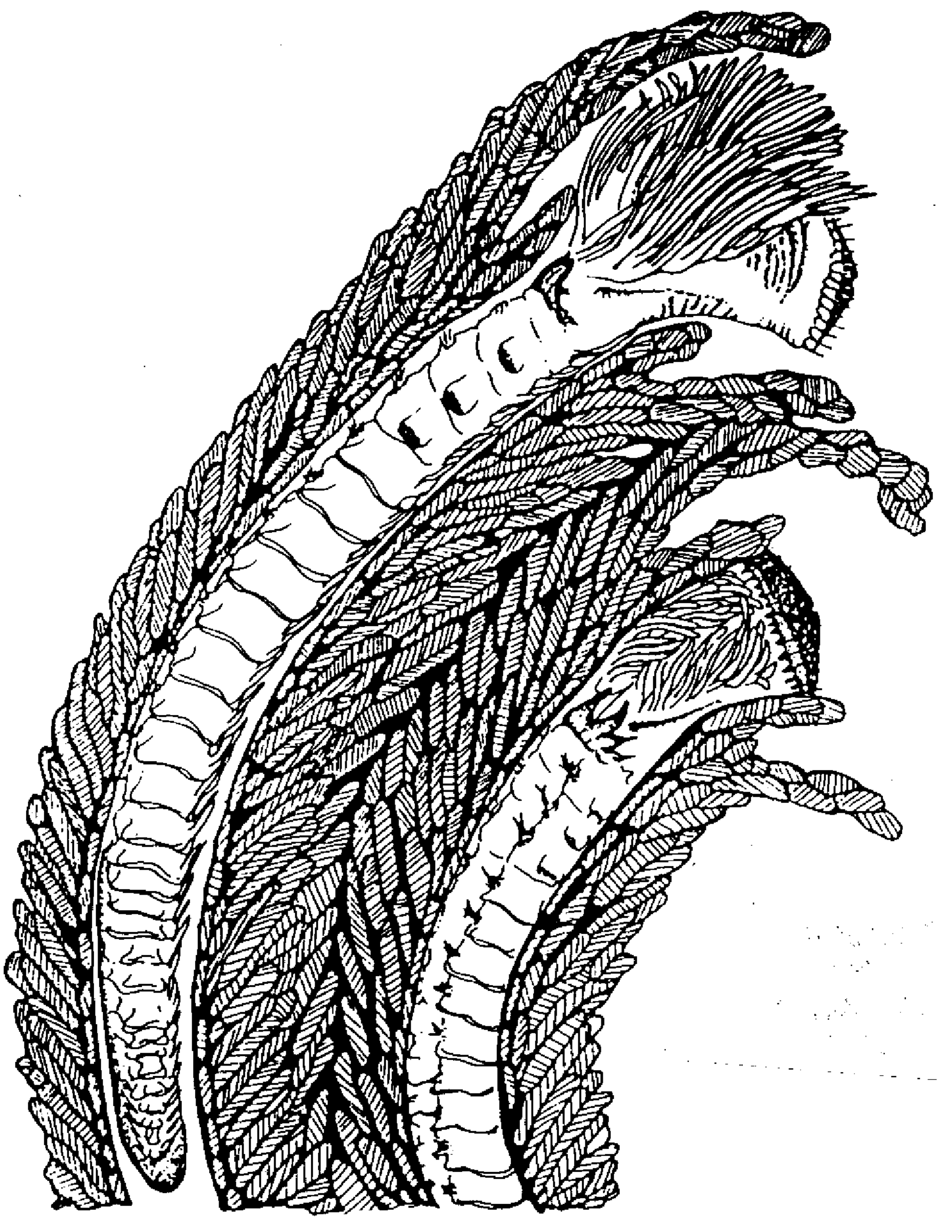
FLSGP-T-85-001 C2

# Criteria for Beach Nourishment : Biological Guidelines for Sabellariid Worm Reef

By Walter G. Nelson and Martin B. Main



FLORIDA SEA GRANT COLLEGE

TECHNICAL PAPER NO. 33

# CRITERIA FOR BEACH NOURISHMENT: BIOLOGICAL GUIDELINES FOR SABELLARIID WORM REEF

Walter G. Nelson
Martin B. Main

Department of Oceanography and Ocean Engineering
Florida Institute of Technology
Melbourne, Florida 32901

Project No. R/C-S-20
Grant No. NA80AA-D-00038

Technical Papers are duplicated in limited quantities for specialized audiences requiring rapid access to information and may receive only limited editing. This paper was compiled by the Florida Sea Grant College with support from NOAA Office of Sea Grant, U.S. Department of Commerce, grant number NA80AA-D-00038. It was published by the Sea Grant Extension Program which functions as a component of the Florida Cooperative Extension Service, John T. Woeste, Dean, in conducting Cooperative Extension work in Agriculture, Home Economics, and Marine Sciences, State of Florida, U.S. Department of Agriculture, U.S. Department of Commerce, and Boards of County Commissioners, cooperating. Printed and distributed in furtherance of the Acts of Congress of May 8 and June 14, 1914. The Florida Sea Grant College is an Equal Employment Opportunity-Affirmative Action employer authorized to provide research, educational information and other services only to individuals and institutions that function without regard to race, color, sex, or national origin.

TECHNICAL PAPER NO. 33
July 1985

TABLE OF CONTENTS

## INTRODUCTION

Beach nourishment is presently the method of choice in Florida for combating severe erosion of beaches where valuable oceanfront property is threatened. Numerous areas along the urbanized southeast and southwest coasts of Florida where erosion problems exist also have sabellariid worm communities, often associated with Anastasia formation rock outcrops occurring in the surf zone. The Anastasia formation, with beach rock outcrops, extends from Anastasia Island opposite St. Augustine southward for 150 mi to Boca Raton. There it grades into the Miami oolite formation. On the west coast, Anastasia beach rock has been observed from a point north of Ten Thousand Islands in Collier county to Siesta Key near Sarasota (Puri and Vernon, 1964). Kirtley and Tanner (1968) identify 4 species of worm of the family Sabellaridae in Florida and show a range distribution of these species from Panama City east and south to Ten Thousand Islands on the Gulf coast and from Amelia Island south to Daytona Beach Shores and again from Cape Canaveral to Miami Beach on the east coast. Concern over possible damage to these habitats has caused Florida Department of Environmental Regulation to deny or delay the issue of permits for beach re-nourishment and inlet sand-bypassing projects in areas where worm communities are known to occur. However, only extremely minimal information on biological parameters of these systems is available for decision making by state permitting agencies.

One of these worm species is of particular interest. Phragmatapoma lapidosa (Fig. 1) is known to create wave resistant reef formations in the intertidal and shallow surf zones (1-4 m) along the south coast of Florida from Cape Canaveral to Key Biscayne (Kirtley, 1966; Gram, 1968; Gore et al., 1978; Kirtley and Tanner, 1968; Kreuger, 1974). These reefs act as anti-erosion agents by decreasing wave action (Multer and Milliman, 1967), and possibly by trapping sand from the littoral drift on the landward side of the reefs (Kirtley and Tanner, 1968). An examination of coastal engineering aspects of worm reefs by Mehta (1973) concluded that they were valuable in reducing coastal erosion. Kirtley and Tanner (1968) report that the worm reef in the intertidal area of south Florida's east coast appears to have a direct relationship with beach rock and may aid in accumulation and lithification of this material. Since the reef and beach rock have high material strength, they are important factors in shoreline development. In essence, these reef structures act as offshore breakwaters. The reef orientation appears to be perpendicular to the prevailing energy, as observed for the southeast trend of the Rio Mar reef at Vero Beach which is perpendicular to the prevailing northeasternly waves. Mehta (1973) suggests this orientation is optimal for sand particle collection by the organisms.

In terms of its impact on sediment distribution, P. lapidosa has been shown to selectively remove finer sand particles for use in tubes, resulting in better sorting of beach sediments (Multer and Milliman, 1967; Gram, 1968), while the reef structures can modify longshore transport (Mehta, 1973). These worms also use heavy minerals and flat shell fragments in their tube building while cracks and crevisses in the reef trap other sediment and shell material, resulting in a change in the sediment distribution pattern of the beaches near reefs.

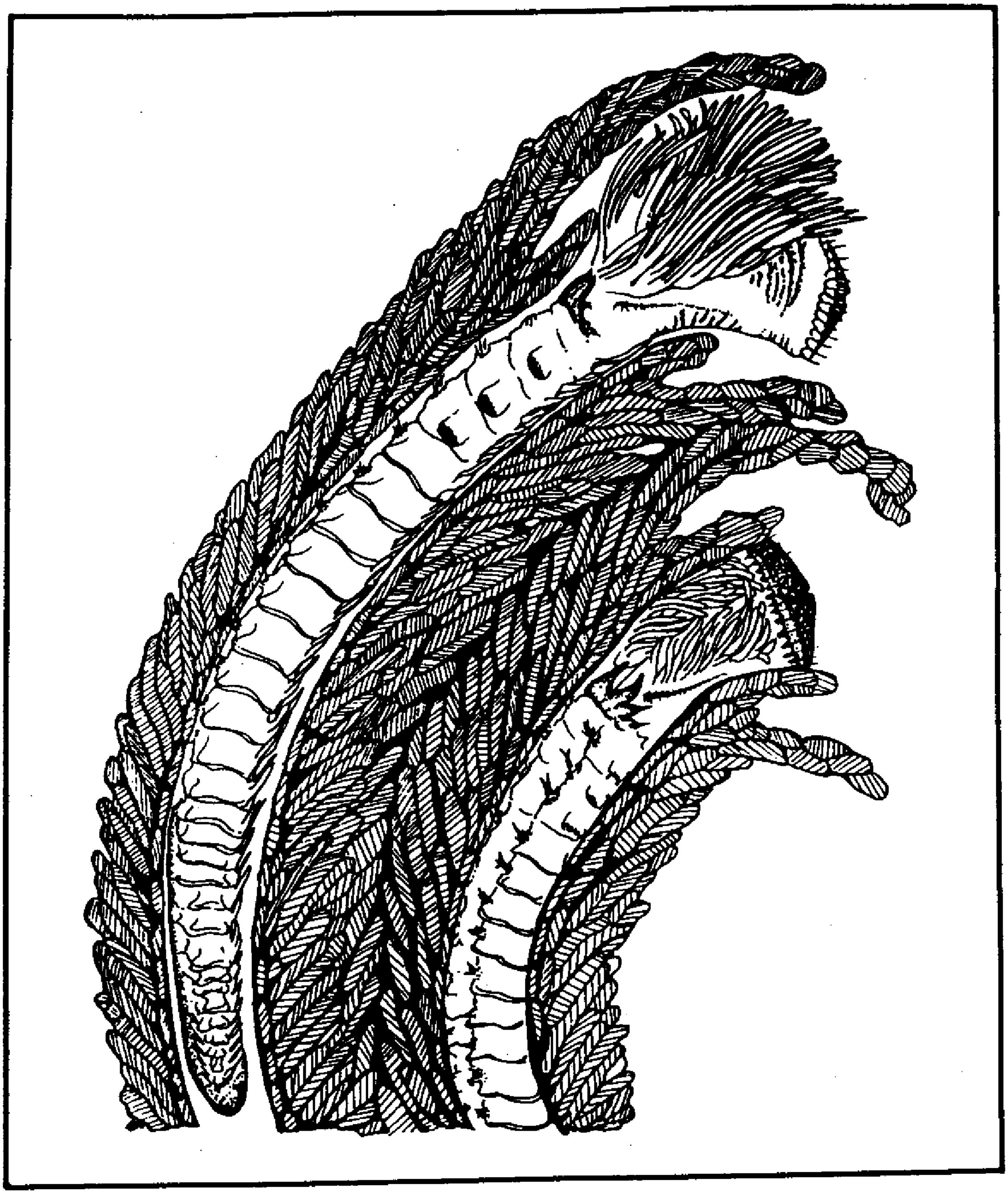


Figure 1. Illustration of Phragmatopoma lapidosa in its sand grain tube. The worm on the left is shown in its feeding position. The worm on the right is shown withdrawn into its tube with the tube entrance blocked by modified setae termed opercular palae. Redrawn from Kirtley, 1966.

The ecological role of worm reefs in the near-shore environment is largely unknown, although some work has been done on larval development and settlement of the worms (Eckelbarger, 1976, 1978; Mauro,1975; Kreuger, 1974). It is known that large numbers of species are associated with the worm reef structures (Gore et al., 1978; Van Montfrans, 1981; H. Rudolph, pers. comm.), significantly increasing species diversity in the relatively species poor surf zone. Thus worm reefs can be presumed to be important elements in the surf zone both from the biological and geological point of view, and concern over damage to these systems is warranted.

In spite of the apparent importance of P. lapidosa reef structures, much basic information needed for making permit decisions is lacking. Specifically, no information is available on the detrimental effects of beach nourishment in the area of worm reefs. Information on stress tolerance of P. lapidosa is limited to the studies of Mulhern (1976) who has described acute oil toxicity for P. lapidosa and Kavanaugh (1979) who has determined the effects of cadmium on this species. No information for P. lapidosa is available on tolerances to sediment burial, siltation or exposure to hydrogen sulfide, all of which might occur during beach nourishment. This is significant since Clark (1978) has described extensive mortality among P. lapidosa following beach nourishment at Sebastian Inlet, Florida, yet the precise cause of the mortality was not clearly determined and natural causes may have been responsible. For example, little is known of th life span of P. lapidosa and it has been suggested that worm reef colony life span may be as little as 3 months in areas of active sand movement (T. Campbell, A. V. Strock & Assocs., pers. comm.).

It has been the purpose of this project to provide the basic biological and geological data together with summary guidelines which will allow Florida Dept. of Environmental Regulation and project engineers to make necessary permitting and design decisions for beach nourishment projects in worm reef areas. Towards this end, the present work seeks to determine the tolerance of P. lapidosa to sediment burial the tolerance of these organisms to exposure to hydrogen sulfide, the tolerances of these organisms to heavy silt loads in the water as well as sediment grain size utilization patterns for this species.

## METHODS

Large pieces of living worm reef were collected for each experiment from the north jetty at the Sebastian Inlet State Recreation Area and transported in containers of seawater to the laboratory where they were cut into blocks of approximately equal size (5x5x8 cm). These samples were immediately transferred to aquaria containing unfiltered, aerated seawater and allowed to acclimate for 24 hours prior to an experiment. Methodogies for individual experiments are described below.

Procedures following each experiment were the same. Upon completion of a designated treatment, samples were placed in aerated aquaria with unfiltered seawater and allowed a recovery period. Recovery periods were of sufficient duration (one hr for the burial and siltation experiments and 6 hrs for the sulfide experiments) to allow the worms to begin actively pumping at the tube openings. Duplicate live counts of worms were made for each sample, with recoil from touch by a dissecting needle being the criterion used to indicate a living worm. Samples were then fixed in a formalin/ rose bengal stain solution and later disaggregated to obtain counts (heads only) of the total abundance of worms for each sample. Per cent survivorship of each sample was determined from the ratio of the mean live count over the total abundance count from the disaggregated sample.

Percent survivorship data were transformed with the angular transformation (arcsin square root) and inspected for compliance to assumptions of normality and homogeneity of variances by the Kolmogorov-Smirnov test and the $F_{max}$ test, respectively. All experimental treatments used three replicates. Analysis of variance (ANOVA) was utilized in each case to determine the significance of treatment effects on survival (Sokal & Rohlf, 1981), while the T-method for unplanned comparisons (Sokal & Rohlf, 1981) was used for comparisons of treatment means.

### Burial Experiments

Burial experiments tested the response of P. lapidosa to burial by five different sediment types over periods of 25, 48 and 72 hrs. The burial materials were beach sediments with grain size distributions (Table 1) ranging from coarse to fine sediments (A, B, C, D), as well as an estuarine muddy sand (E). The estuarine muddy sand was similar in grain size distribution to the finest fraction of the beach sediment (Table 1), but contained approximately twice the organic matter. All beach sediments were obtained from the ocean beach adjacent to the laboratory and were wet sieved to obtain the appropriate size classes. The estuarine muddy sand was collected from the Indian River lagoon approximately one mile south of the Sebastian Inlet and was not sieved. All sediments were allowed to air-dry prior to use, and subsamples of each material were analysed for grain size distribution. Although separate collections of sediment were made for the February and July experiments, Table 1 indicates that the grain size distributions of the treatments used in each experiment were basically similar. The control consisted of worm reef blocks unexposed to sediment burial. Burial experiments were conducted in February (1-4, 21-24) and July (8-11), 1984. The first February experiment tested beach

Table 1. Grain size analysis of sediments used in the burial experiments. Values are weight percent. Sediment types A, B, C, D are sieved fractions of beach sand; type E is unsieved estuarine sediment.

February Experiments

| | Sieve Size (mm) | | | | | | |
|---|---|---|---|---|---|---|---|
| Sediment Type | 4 | 2 | 1 | 0.5 | 0.25 | 0.125 | 0.625 |
| A | 23.4 | 59.4 | 15.2 | 1.6 | | | |
| B | | 9.6 | 83.7 | 6.6 | 0.1 | | |
| C | | | 15.8 | 65.2 | 24.6 | 3.8 | 0.1 |
| D | | | | 0.1 | 31.7 | 41.1 | 25.6 |
| E | 0.3 | 0.5 | 1.3 | 13.4 | 32.5 | 23.8 | 25.5 |

July Experiment

| | Sieve Size (mm) | | | | | | |
|---|---|---|---|---|---|---|---|
| Sediment Type | 4 | 2 | 1 | 0.5 | 0.25 | 0.125 | 0.625 |
| A | 24.5 | 60.1 | 13.8 | 1.1 | 0.3 | 0.1 | 0.3 |
| B | | 11.8 | 81.1 | 6.0 | 0.8 | 0.2 | 0.1 |
| C | | 0.7 | 12.9 | 56.3 | 26.7 | 3.1 | 0.2 |
| D | 0.3 | 1.1 | 7.1 | 5.1 | 30.4 | 35.8 | 19.7 |
| E | 0.5 | 0.9 | 1.8 | 11.6 | 36.0 | 23.4 | 24.8 |

Table 2. Salinity and temperature fluctuations during the February and July burial experiments.

| Date | Salinity (ppt) | | Temperature (°C) | |
|---|---|---|---|---|
| | Range | Mean | Range | Mean |
| February 1-4 | 34-35 | 34.8 | 17.0-20.0 | 18.3 |
| February 21-24 | 34-35 | 34.8 | 18.5-23.0 | 21.5 |
| July 8-11 | 35-36 | 35.5 | 28.0-30.5 | 29.2 |

sediments A and D (Table 1), while the second tested sediment types C, D and E. All five sediment types were tested simultaneously in the July experiment. Studies were conducted in February and July to determine whether there might be seasonal differences in the response of P. lapidosa to the burial treatments. Seawater in the tanks was exchanged daily for fresh seawater transported directly from the ocean.

Experimental design consisted of four 15 l aquaria partitioned into three sections with plexiglass dividers to assist in location of sets of samples. Each section housed three samples of P. lapidosa which were placed in a vertical orientation on a layer of beach sand. All sections of the aquaria received aeration continuously during the experiment. Burial treatment consisted of instantaneous burial to a depth of approximately 18 cm (dictated by aquarium height) by a given type of sediment. Salinity and water temperature were measured daily.

Siltation Experiment

The siltation experiment was designed to determine the mortality of P. lapidosa in response to high concentrations of suspended silt. Twelve replicate sample blocks of worm reef were placed in each of four 15 l aquaria. Blocks were held in place by a weighted wood dowel framework to prevent damage to blocks resulting from the water movement in the aquaria required to keep the silt in suspension. Silt loads were added to the tanks by dry weight, with treatments consisting of a control (no silt), 2.0, 4.0 and 6.0 g/l. The silt utilized in these experiments was commercially available Fuller's earth (Fisher No. F-90, technical grade). Fuller's earth is composed of attapulgite and montmorillonite, two naturally occurring clays. The median grain size of Fuller's earth is reported to be less than 0.0005 mm, and 82% of the particles are less than 0.002 mm (O'Conner et al., 1977; Sherk et al., 1976). Suspension of the silt was maintained by a continuously operating motor which propelled a single paddle in each tank at a rate of 17 full strokes per minute. Turbidity levels were measured daily by analysing water samples with a Hach 2100A Turbidimeter.

Three replicate samples of worm reef were removed from each of the treatment tanks at intervals of 24, 48, 72 and 96 hrs. Salinity, temperature and dissolved oxygen were recorded daily throughout the experiment. The siltation experiment was performed from June 7-11, 1984.

Sulfide Toxicity Experiments

Two separate studies were performed, a preliminary 12 hr study and a second 48 hr study. Experimental sulfide treatments were prepared using both deoxygenated and oxygenated seawater, using seawater obtained from the region of the Gulf Stream. The seawater had first been filterred with 0.3 micron glass fiber filters. Oxygen was stripped from the seawater by bubling nitrogen through it. Dissolved oxygen levels were measured with a YSI Model 57 Dissolved Oxygen meter and oxygen probe which had been checked for accuracy with the Winkler titration method. Dissolved oxygen levels were adjusted to <0.2 mg/l and 6.0 mg/l for the deoxygenated and oxygenated treatments, respectively. Sulfide treatments were prepared according to general procedures as outlined by Theede et al. (1969). Stock solutions were prepared by dissolving 5 g of $Na_2S \cdot 9H_2O$ per 1 with serial dilution to appropriate experimental concentrations. A total of nine treatments were tested in the preliminary 12 h study. These consisted of two controls without sulfide addition (C = oxygenated seawater, N = deoxygenated seawater), sulfide concentrations on the order of magnitude of $10^{-4}$M in both types of seawater (AS4 = oxygenated, NS4 = deoxygenated), on the order of magnitude of $10^{-6}$M in both types of seawater (AS6 = oxygenated, NS6 = deoxygenated) and on the order of magnitude of $10^{-9}$M in both types of seawater (AS9 = oxygenated, NS9 = deoxygenated). The 48 hr study omitted the $10^{-9}$M concentrations. Concentrations of $H_2S$ measured in the stock solutions were 4.3 mg/l and .048 mg/l for the $10^{-4}$ and $10^{-6}$ levels, respectively, for the 48 hr experiment.

Worm reef samples were placed into 0.95 l glass jars containing the treatment solutions and the jars were sealed with screw caps. In both experiments, three replicates per treatment were used. All treatments were analysed for sulfide content at the beginning and end of the experiments by photometric procedures as described in Standard Methods for the Examination of Water and Wastewater, 15th edition (1980). Both experiments were conducted in the laboratory at 23° C during December 1984.

Sediment Analysis

Samples of living worm reef were collected from six locations along Florida's southeast coast. These locataions were:

1. Bear Cut; Key Biscayne, Dade Co., (south side of channel).
2. Boynton Inlet; Palm Beach Co., (south beach).
3. Jupiter Inlet; Palm Beach Co., (north beach).
4. Fort Pierce Inlet; Indian River Co., (inside the inlet).
5. Vero Beach, St. Lucie Co., (pier piling, north Vero Beach).
6. Sebastian Inlet; Brevard Co. (north jetty).

Sample locations 1-3 were sampled August 25-26, 1984, locations 4-5 on June 8, 1984, and location six on May 12 and November 2, 1984. Worm reef samples were fixed in a formalin-seawater solution for transportation to the laboratory where they were cut into three smaller samples each approximately 5x5x5 cm in size. For each sample, the inner diameter of the worm tube openings were measured with calipers for 25 individuals. Additionally, the number of tube openings per $cm^2$ was measured. Samples were then mechanically disaggregated and immersed in chlorine bleach until all organic matter had been dissolved (Multer & Milliman, 1967). These samples were then repeatedly washed with distilled water, each time allowing the fine particles to settle before decanting and repeating the procedure. Samples were dried at 90° C for at least 12 hrs, and then sieved using U. S. standard sieves at 1 phi intervals. The calcium carbonate content was determined for each size class of sediment via acid digestion (Multer & Milliman, 1967). Sediment samples were also taken from beaches adjacent to the sites of the worm reef collections and were analysed for grain size distribution and calcium carbonate content. To determine whether P. lapidosa selects certain grain sizes for tube building, a concentration factor was computed as given by Multer & Milliman (1967) and Scholl (1958). This factor is simply the ratio of the weight percent in a given size class of worm reef sand to that of the beach sand. A value greater than 1.0 indicates that the worm is preferentially sorting sediment of this grain size from the beach sand (Multer & Milliman, 1967). Mean and median grain sizes, sorting and skewness (Inman, 1952) were averaged for the replicated samples from each location.

## RESULTS

### Burial Experiments

Salinity data recorded during the burial experiments show little fluctuation in salinity due to the daily changes of water in the aquaria. Temperature regimes were considerably lower in the February experiments than in the July study (Table 2).

The percent survival data for the burial experiments were analyzed using two-way ANOVA with replication. Analyses of the February experiments indicate mortality was not significantly different among sediment treatments in either experiment. A significant time effect was present, however, in both of the February studies (Table 3), indicating an increased mortality for all treatments the longer the animals were held in the laboratory. The interaction term was non-significant in both cases.

Different results were found for the single July experiment. As in the February experiment, a significant increase in mortality over time occured. A highly significant effect due to sediment type was observed, and the interaction of sediment type and duration of the experiment was also significant (Table 4).

Graphical comparison of the group means using the T-method for unplanned comparisons (Sokal & Rohlf, 1981) indicates that for the first 24 hrs, no significant differences in survival existed among the different sediment treatments, nor does survival differ significantly among the controls over the 72 hr of the experiment (Fig. 2). Survival decreases significantly after 48 hrs for all treatments where sediment was added. After 72 hrs, the finer beach sediments (type D) and the estuarine muddy sand (E) caused the highest mortality of all treatments, while that for the coarser sediments was not greatly different from that for the 48 hr treatment. It is this disproportionate mortality in the fine sediment treatments at 72 hrs which presumably gives rise to the significant interaction term.

### Siltation Experiment

For the siltation experiment, turbidity measurements were made at the begining of the experiment to obtain background turbidity levels (initial), immediately after silt addition ($t = 0$), and daily for the 4 day duration of the experiment. Table 5 summarizes the turbidity data. Background turbidity data resulted from the filling of the aquaria with the seawater which had been transported from the surf zone, an area where turbidity is generally high due to wave activity. Background turbidity decreased with time in the control tank until 48 hrs, after which it remained relatively constant. In the silt addition treatments, the increased turbidities at 96 hrs versus 24 hrs reflect increased sediment suspension as samples, which tended to baffle the wave action, were removed from the aquaria. Salinity remained constant throughout the experiment at 36 ppt. Temperatures ranged from 26 - 26.8° C, while dissolved oxygen ranged from 5.9 - 6.0 mg/l.

The percent survival data from the siltation experiment were analysed using a two-way ANOVA with replication (Table 6 ). Survival was not significantly different among the silt treatments and no signi-

Table 3. Two-way analysis of variance results comparing percent survivorship (arcsin square root transformed) among treat- for the two February burial experiments. Grain size distributions for the sediment types used are given in Table 1.

Experiment 1. Feb. 1-4, 1984.
Sediment treatments: control, A, D.
Time treatments: 25, 48, 72 hrs.

| Source of Variation | df | Mean Square | F | Significance |
|---|---|---|---|---|
| Sediments | 2 | 0.869 | 0.012 | $p>.05$ |
| Time | 2 | 368.095 | 5.241 | $p<.05$ |
| Interaction | 4 | 105.256 | 1.499 | $p>.05$ |
| Error | 18 | 70.237 | | |

Experiment 2. Feb. 21-24, 1984.
Sediment treatments: control, B, C, E.
Time treatments: 25, 48, 72 hrs.

| Source of Variation | df | Mean Square | F | Significance |
|---|---|---|---|---|
| Sediments | 3 | 21.260 | 0.568 | $p>.05$ |
| Time | 2 | 659.227 | 17.624 | $p<.05$ |
| Interaction | 6 | 36.285 | 0.970 | $p>.05$ |
| Error | 24 | 37.405 | | |

Table 4. Two-way analysis of variance results comparing percent survivorship (arcsin square root transformed) among treatments for the July burial experiment. Grain size distributions for the sediment types used are given in Table 1.

July 8-11, 1984.
Sediment treatments: control, A, B, C, D, E.
Time treatments: 25, 48, 72 hrs.

| Source of Variation | df | Mean Square | F | Significance |
|---|---|---|---|---|
| Sediments | 5 | 1559.63 | 25.49 | $p<.001$ |
| Time | 2 | 3490.55 | 57.05 | $p<.001$ |
| Interaction | 10 | 380.57 | 6.22 | $p<.001$ |
| Error | 36 | 61.18 | | |

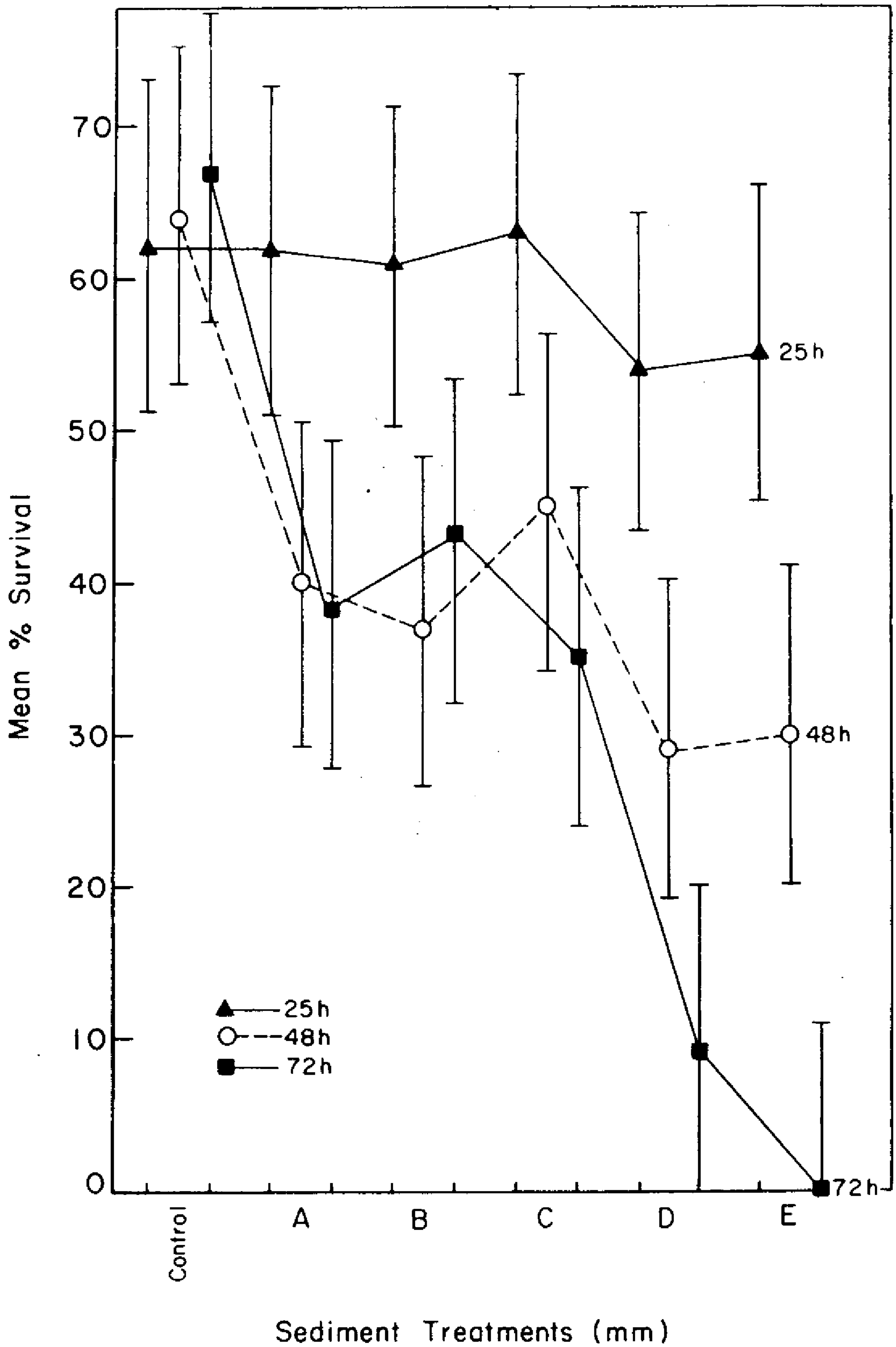



Figure 2. Mean percent survivorship of Phragmatopoma lapidosa at 25, 48 and 72 hrs following burial by 5 different sediment types for the July experiment. Grain size distributions for each sediment type are given in Table 1.

Table 5. Turbidity data for the duration of the siltation experiment. Data are nephlometric turbidity units (ntu).

| Treatment | Initial | Time Elapsed (hrs) 0 | 24 | 48 | 72 | 96 |
|---|---|---|---|---|---|---|
| Control | 20 | 23 | 12 | 6 | 5 | 6 |
| 2.0 g/l | 37 | 1625 | 1150 | 1000 | 1200 | 1300 |
| 4.0 g/l | 26 | 2625 | 1875 | 2062 | 2562 | 2875 |
| 6.0 g/l | 24 | 3812 | 3000 | 3125 | 3562 | 3750 |

Table 6. Two-way analysis of variance results comparing percent survivorship (arcsin square root transformed) among treatments for the siltation experiment.

June 7-11, 1984.
Silt treatments: control, 6.0 g/l, 4.0 g/l, 2.0 g/l.
Time treatments: 24, 48, 72, 96 hrs.

| Source of Variation | df | Mean Square | F | Significance |
|---|---|---|---|---|
| Silt | 3 | 59.620 | 1.782 | $p>.05$ |
| Time | 3 | 300.437 | 8.979 | $p<.001$ |
| Interaction | 9 | 45.905 | 1.372 | $p>.05$ |
| Error | 32 | 33.459 | | |

Table 7. One-way analysis of variance results comparing percent survivorship (arcsin square root transformed) among treatments for the 12 hr exposure to sulfide experiment. Treatments listed below are described in the text.

December 3-4, 1984.
Sulfide treatments: C, N, AS4, NS4, AS6, NS6, AS9, NS9.

| Source of Variation | df | Mean Square | F | Significance |
|---|---|---|---|---|
| Sulfide | 7 | 38.542 | 1.837 | $p>.05$ |
| Error | 16 | 20.976 | | |

ficant interaction effect was present. Survival of the organisms was found to decrease significantly with time.

Sulfide Toxicity Experiments

Survival data from the initial 12 hr study were analysed using one-way ANOVA. ANOVA results indicate that for periods of up to 12 hrs, survival is not significantly affected by the sulfide treatments tested (Table 7).

Survival data from the 48 hr experiment was analyzed with a two-way ANOVA with replication, which indicated significantly different effects on survival by the various treatments (Table 8). Mortality was shown to increase significantly over the duration of the experiment. The interaction term of concentration of sulfide versus duration of exposure was also significant.

Comparison of the group means (T-method, Sokal & Rohlf, 1981) for the first 24 hrs indicates that mean survival did not differ significantly among treatments (Fig. 3). After 48 hrs, the control treatments (C,N) did not differ significantly from any of the 24 hr treatments, while the treatments containing sulfide caused significantly greater mortality than all but one of the 24 hr treatments. The treatment containing the highest sulfide level together with deoxygenated seawater (NS4) caused significantly greater mortality than all other treatments after 48 hr (Fig. 3). The response of the worms in this treatment is probably largely responsible for the significant interaction term between sulfide concentration and duration of exposure.

Initial stock concentrations of 4.5 mg S/l and 0.05 mg S/l were used to prepare the $10^{-4}$M and $10^{-6}$M treatments, respectively (Fig. 4). Analysis of sulfide concentrations in experimental jars at 24 hrs indicates that sulfide concentrations were generally below initial concentrations, with the exception of the NS6 treatment. The reduction of sulfide concentrations is presumably the result of interaction with oxygen either present in the water (AS6, AS4), or through oxygen entering the jars over time (NS6, NS4). The rank order of sulfide concentrations at this time follows the order predicted based on treatments, however. After 48 hrs, sulfides are present in jars of all treatments at concentrations not related to original treatment levels, indicating sulfide production in the jars was occurring at this point.

Sediment Analysis

Summary grain size statistics for sediments from worm tubes are given in Table 9 while statistics for samples from the adjacent beach are given in Table 10. Mean sediment grain size of worm reef sediments ranged from 1.3 - 1.83 phi (Table 9) as compared with a range of 0.33 - 2.87 phi (Table 10) from beach sediments. Worm reef samples were all well to moderately sorted (Table 9). Beach sediments for Jupiter Inlet and Fort Pierce Inlet were the only samples which were poorly sorted (Table 10). No consistent pattern of skewness was seen for either the worm reef or beach samnples (Tables 9, 10).

Tables 11 and 12 give the complete size distribution data for both the worm reef and beach samples. Figure 5 compares the mean and median grain size for worm reef and beach samples. This figure indi-

Table 8. Two-way analysis of variance results comparing percent survivorship (arcsin square root transformed) among treatments for the 48 hr exposure to sulfide experiment. Treatments listed below are described in the text.

December 17-19, 1984.
Sulfide treatments: C, N, AS4, NS4, AS6, NS6.
Time treatments: 24, 48 hrs.

| Source of Variation | df | Mean Square | F | Significance |
|---|---|---|---|---|
| Sulfide | 5 | 213.88 | 5.65 | $p<.05$ |
| Time | 1 | 2409.41 | 83.46 | $p<.001$ |
| Interaction | 5 | 163.10 | 7.41 | $p<.001$ |
| Error | 24 | 28.87 | | |

Table 9. Summary statistics (phi units) for the analysis of sediment derived from living worm reef.

| Location | Median | Mean | Sorting | Skewness |
|---|---|---|---|---|
| Sebastian Inlet (5/12) | 1.31 | 1.37 | 0.63 | 0.10 |
| Sebastian Inlet (11/2) | 1.15 | 1.30 | 0.69 | 0.22 |
| Vero Beach | 1.55 | 1.69 | 0.83 | 0.08 |
| Fort Pierce Inlet | 0.99 | 1.32 | 0.91 | 0.36 |
| Jupiter Beach | 1.78 | 1.83 | 0.62 | 0.08 |
| Boynton Inlet | 1.68 | 1.44 | 0.44 | -0.55 |
| Bear Cut | 1.50 | 1.55 | 0.71 | 0.07 |

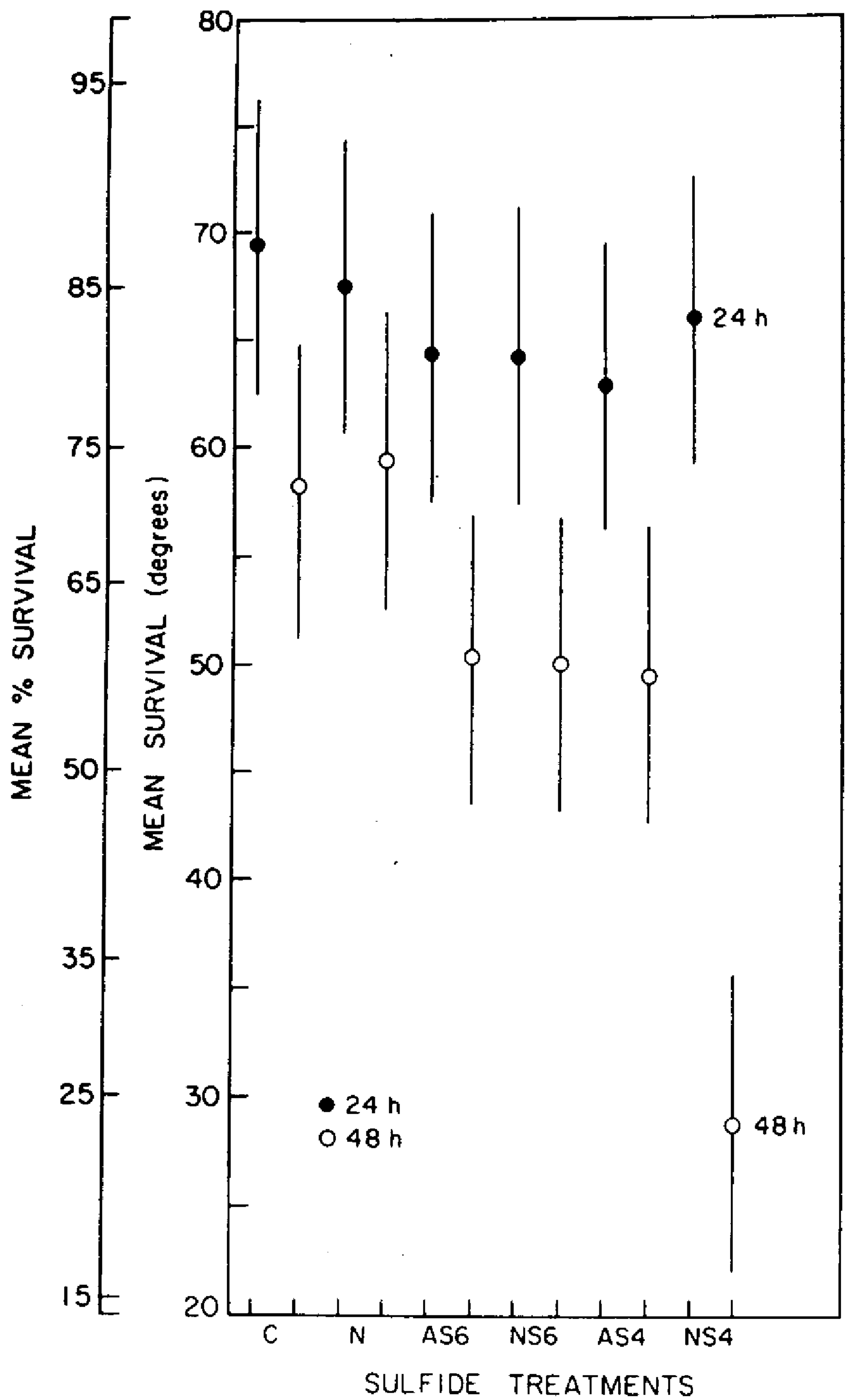



Figure 3. Mean survivorship shown both as percent and as degrees (arcsin square root transformed data) for *Phragmatopoma lapidosa* at 24 and 48 hrs following exposure to $H_2S$. A description of each treatment is given in the text.

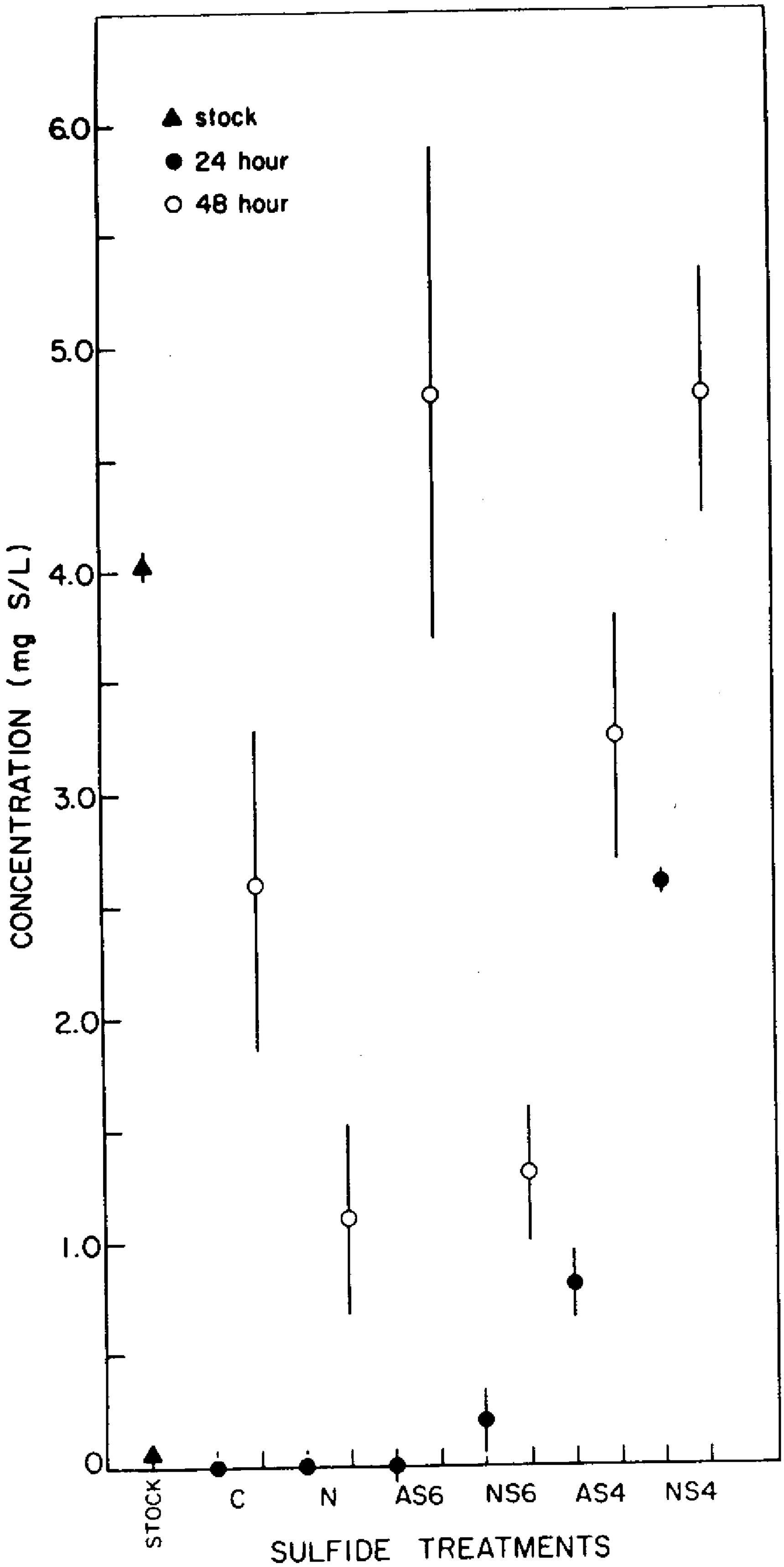



Figure 4. Concentrations of $H_2S$ at 24 and 48 hrs for each treatment. Stock solution concentrations are also indicated.

Table 10. Summary statistics (phi units) for the analysis of sediment from beaches adjacent to worm reef.

| Location | Median | Mean | Sorting | Skewness |
|---|---|---|---|---|
| Sebastian Inlet (5/12) | 1.48 | 1.37 | 0.77 | -0.14 |
| Sebastian Inlet (11/2) | 0.72 | 0.68 | 0.68 | -0.06 |
| Vero Beach | 1.94 | 2.05 | 0.75 | 0.15 |
| Fort Pierce Inlet | 0.30 | 0.33 | 1.06 | 0.03 |
| Jupiter Beach | 2.48 | 2.87 | 1.21 | 0.32 |
| Boynton Inlet | 2.51 | 2.50 | 0.38 | -0.03 |
| Bear Cut | 1.11 | 1.04 | 0.69 | -0.10 |

Table 17. Measurements of average inner diameter of tubes and average tube density per $cm^2$ for <u>Phragmatopoma lapidosa</u> for locations along the southeast coast of Florida.

| Location | Inner Diameter (cm) | Std. Dev. | Density (No./$cm^2$) |
|---|---|---|---|
| Sebastian Inlet (5/12) | 0.17 | 0.02 | 5.8 |
| Sebastian Inlet (11/2) | 0.18 | 0.01 | 4.4 |
| Vero Beach | 0.18 | 0.01 | 4.2 |
| Fort Pierce Inlet | 0.20 | 0.01 | 2.8 |
| Jupiter Beach | 0.20 | 0.01 | 5.3 |
| Boynton Inlet | 0.21 | 0.01 | 4.8 |
| Bear Cut | 0.17 | 0.01 | 2.0 |

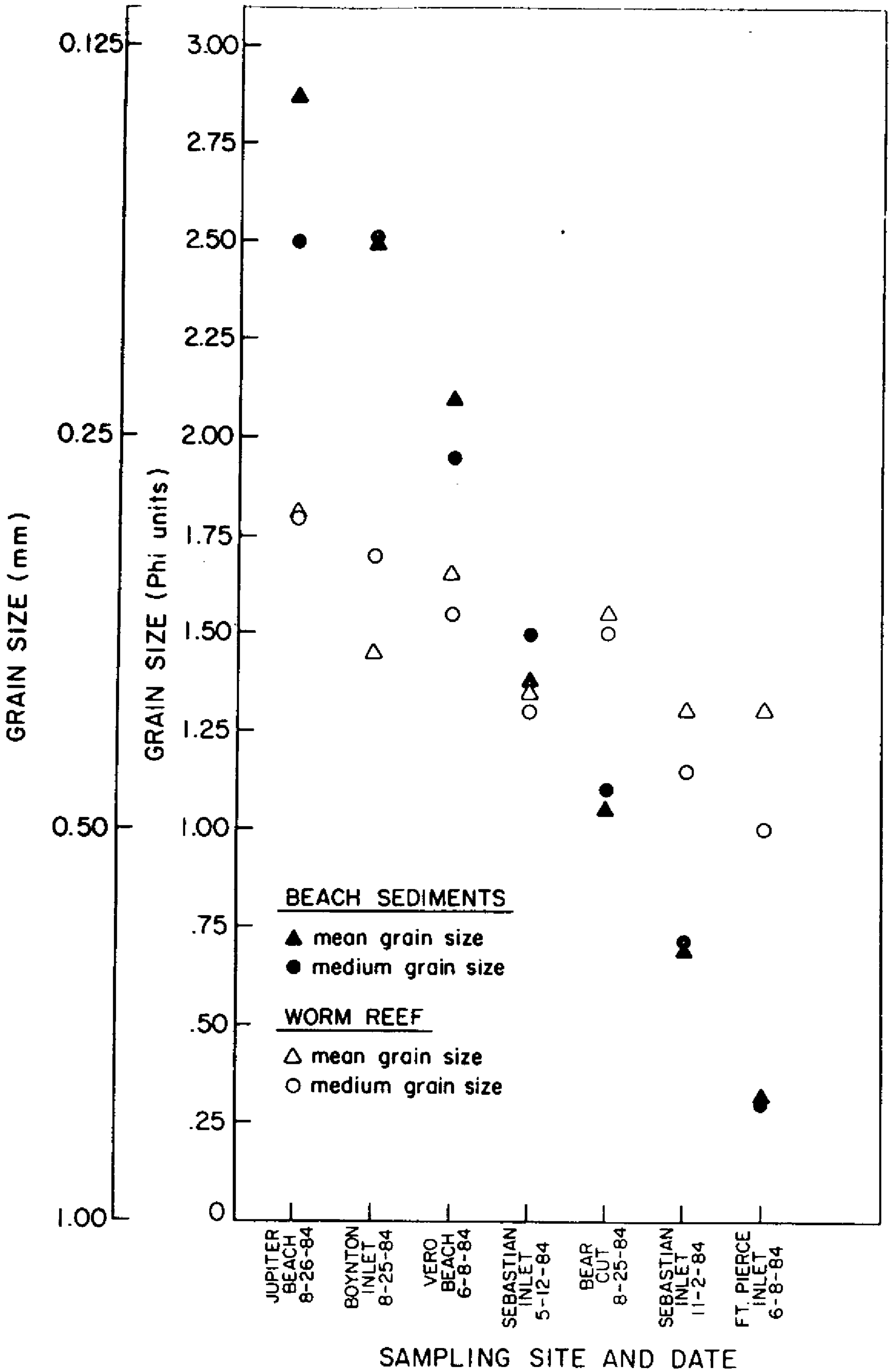



Figure 5. Comparison of mean and median grain size for worm reef sediment versus sediment from adjacent beaches for sample sites along the southeast coast of Florida.

Table 11. Size distribution of sediment from worm reef samples. Values are mean weight percent.

| Location | 4.0 | 2.0 | 1.0 | Size Fraction (mm) 0.5 | 0.25 | 0.125 | 0.625 | <0.625 |
|---|---|---|---|---|---|---|---|---|
| Sebastian Inlet (5/12) | --- | --- | 0.6 | 33.0 | 50.8 | 9.8 | 5.2 | 0.6 |
| Sebastian Inlet (11/2) | 0.1 | 0.2 | 0.9 | 42.4 | 41.0 | 10.4 | 4.0 | 1.0 |
| Vero Beach | --- | 0.1 | 1.0 | 21.2 | 52.1 | 16.2 | 7.5 | 1.9 |
| Fort Pierce Inlet | --- | 0.1 | 4.0 | 46.1 | 31.6 | 9.2 | 7.8 | 1.2 |
| Jupiter Beach | --- | --- | 0.1 | 8.3 | 59.5 | 27.2 | 2.3 | 2.6 |
| Boynton Inlet | --- | --- | 0.4 | 15.5 | 53.2 | 28.2 | 2.3 | 0.4 |
| Bear Cut | --- | 0.2 | 0.9 | 22.5 | 54.2 | 19.0 | 0.9 | 2.4 |

Table 12. Size distribution of sediment from beach samples. Values are mean weight percent.

| Location | 4.0 | 2.0 | 1.0 | Size Fraction (mm) 0.5 | 0.25 | 0.125 | 0.625 | <0.625 |
|---|---|---|---|---|---|---|---|---|
| Sebastian Inlet (5/12) | --- | 0.8 | 5.6 | 18.8 | 52.5 | 22.0 | 0.1 | 0.4 |
| Sebastian Inlet (11/2) | --- | 0.8 | 15.2 | 48.5 | 33.7 | 1.7 | 0.1 | --- |
| Vero Beach | --- | 0.5 | 15.7 | 5.3 | 43.0 | 39.0 | 10.5 | --- |
| Fort Pierce Inlet | 4.2 | 6.7 | 26.1 | 39.7 | 16.4 | 4.6 | 2.4 | 0.1 |
| Jupiter Beach | --- | 0.1 | 0.4 | 4.2 | 21.1 | 49.8 | 1.2 | 23.3 |
| Boynton Inlet | --- | --- | 0.1 | 0.9 | 8.4 | 82.3 | 8.0 | 0.2 |
| Bear Cut | --- | 0.8 | 6.2 | 33.5 | 51.7 | 7.7 | --- | --- |

Table 13. Concentration factors (weigth % worm reef / weight % beach sand) for each sediment size fraction.

| | Size Fraction (mm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Location | 4.0 | 2.0 | 1.0 | 0.5 | 0.25 | 0.125 | 0.625 | <0.625 |
| Sebastian Inlet (5/12) | --- | 0.0 | 0.1 | 1.8 | 1.0 | 0.5 | 86.7 | 1.7 |
| Sebastian Inlet (11/2) | --- | 0.2 | 0.1 | 0.9 | 1.2 | 6.0 | 36.4 | 48.5 |
| Vero Beach | --- | 0.3 | 0.1 | 4.0 | 1.2 | 0.4 | 0.7 | 9.4 |
| Fort Pierce Inlet | --- | 0.0 | 0.2 | 1.2 | 1.9 | 2.0 | 3.3 | 23.8 |
| Jupiter Beach | --- | 0.2 | 0.2 | 2.0 | 2.8 | 0.6 | 1.9 | 0.1 |
| Boynton Inlet | --- | 0.3 | 4.4 | 17.2 | 6.3 | 0.3 | 0.3 | 1.7 |
| Bear Cut | --- | 0.3 | 0.1 | 0.7 | 1.1 | 2.5 | 28.7 | 118.0 |

Table 14. Mean percent carbonate for each sediment size fraction for the worm reef sediment.

| | Size Fraction (mm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Location | 4.0 | 2.0 | 1.0 | 0.5 | 0.25 | 0.125 | 0.625 | <0.625 |
| Sebastian Inlet (5/12) | --- | 90.0 | 96.4 | 96.2 | 93.2 | 64.9 | 19.3 | 20.5 |
| Sebastian Inlet (11/2) | 90.7 | 81.3 | 95.8 | 96.8 | 92.8 | 72.3 | 19.3 | 16.6 |
| Vero Beach | --- | 100 | 95.6 | 81.5 | 77.0 | 76.4 | 23.4 | 15.8 |
| Fort Pierce Inlet | --- | 58.3 | 98.9 | 93.0 | 89.0 | 70.4 | 18.4 | 25.2 |
| Jupiter Beach | --- | 100 | 92.3 | 88.3 | 84.5 | 85.5 | 59.2 | 64.6 |
| Boynton Inlet | --- | 100 | 91.4 | 91.7 | 93.3 | 87.1 | 58.6 | 80.7 |
| Bear Cut | --- | 33.3 | 92.3 | 88.3 | 84.5 | 85.5 | 59.2 | 64.6 |

Table 15. Mean percent carbonate for each sediment size fraction for the beach samples.

| Location | Size Fraction (mm) 4.0 | 2.0 | 1.0 | 0.5 | 0.25 | 0.125 | 0.625 | <0.625 |
|---|---|---|---|---|---|---|---|---|
| Sebastian Inlet (5/12) | --- | 99.6 | 93.8 | 59.3 | 24.8 | 20.4 | 8.4 | 13.5 |
| Sebastian Inlet (11/2) | --- | 99.1 | 94.0 | 59.2 | 26.8 | 21.5 | 20.0 | 66.7 |
| Vero Beach | --- | 99.6 | 98.4 | 71.7 | 25.1 | 20.5 | 8.2 | 10.3 |
| Fort Pierce Inlet | --- | 99.3 | 96.7 | 70.9 | 38.0 | 27.0 | 9.6 | 11.4 |
| Jupiter Beach | --- | 100 | 69.0 | 89.1 | 54.7 | 35.6 | 9.7 | 15.7 |
| Boynton Inlet | --- | 100 | 94.3 | 74.3 | 40.9 | 36.8 | 18.6 | 10.5 |
| Bear Cut | --- | 100 | 69.0 | 89.1 | 54.7 | 35.6 | 9.7 | 15.7 |

Table 16. Concentration factors for carbonate (weigth % worm reef / weight % beach sand) for each sediment size fraction.

| Location | Size Fraction (mm) 4.0 | 2.0 | 1.0 | 0.5 | 0.25 | 0.125 | 0.625 | <0.625 |
|---|---|---|---|---|---|---|---|---|
| Sebastian Inlet (5/12) | --- | 0.9 | 1.0 | 1.6 | 3.8 | 3.2 | 2.3 | 1.5 |
| Sebastian Inlet (11/2) | --- | 0.8 | 1.1 | 1.6 | 3.3 | 3.2 | 0.9 | 0.4 |
| Vero Beach | --- | 1.0 | 1.0 | 1.1 | 3.1 | 3.7 | 2.9 | 1.5 |
| Fort Pierce Inlet | --- | 0.6 | 1.0 | 1.3 | 2.3 | 2.6 | 1.9 | 2.2 |
| Jupiter Beach | --- | 1.0 | 1.3 | 1.0 | 1.5 | 2.4 | 6.1 | 4.1 |
| Boynton Inlet | --- | 1.0 | 1.0 | 1.2 | 2.3 | 2.1 | 3.2 | 7.7 |
| Bear Cut | --- | 0.3 | 1.3 | 1.0 | 1.5 | 2.4 | 6.1 | 4.1 |

cates that the mean grain size selected by the worms fell in a considerably smaller range (0.5 - 0.25 mm) than that for the beach sediments (0.84 - 0.125 mm). On beaches with relatively coarse sands (Fort Pierce, Sebastian Inlet 11-2, Bear Cut) the worms concentrated finer sand fractions relative to the beach sand. On beaches with finer sands (Jupiter, Boynton, Vero Beach), the worms tended to concentrate coarser size fractions relative to the beach sediment. Concentration factors for all sediment size classes are given in Table 13, and confirm the relationship suggested by Fig. 5. At all sites except Jupiter Beach, which had the finest mean grain size sediments of the locations sampled , the worms concentrated particles less than 0.063 mm.

The mean percent of carbonate, an indication of shell material, is given for each size class for the worm reef samples (Table 14) and the beach samples (Table 15). Percentage carbonate decreased with decreasing grain size for both types of samples. Table 16 gives the concentration factor for carbonate in each size fraction, indicating a tendency for the worms to concentrate carbonate fractions in most cases in the finer grain sizes.

The mean inner diameter of worm reef tubes ranged from 0.17 - 0.21 mm (Table 17). The mean number of tubes per $cm^2$ ranged from 2.0 - 5.8 (Table 17).

## DISCUSSION

### Burial Experiments

The response patterns of Phragmatopoma lapidosa to the types of environmental disturbance which might be associated with beach nourishment are variable depending on the nature of the stress and the physical environmental conditions in which the stress is applied. For example, the results of the burial experiment indicate that P. lapidosa can tolerate burial by any of the tested sediment types for up to 25 hours without suffering significantly increased mortality. At relatively cooler temperatures (17 - 23 ° C), burial by any of the sediment types results in no significant increase in mortality relative to controls for up to 72 hrs. However, at warmer temperatures (28 - 31° C), significantly increased mortality occurs after 48 hrs for all sediment types. At higher temperatures, mortality due to burial by fine sediments was greatly increased. The statistical analysis suggests the presence of a synergistic interaction between fine sediment size and duration of burial which is particularly harmful at higher water temperatures.

Water termperature may influence survivorship in several ways. Firstly, solubility of oxygen in seawater is less at higher temperatures (Riley & Skirrow, 1965). Secondly, respiratory demands will be greater at higher temperatures, and it has been noted for a variety of marine organisms that mortality is increased at low oxygen levels when temperature is high (Vernberg & Vernberg, 1972). The decrease in porosity of fine sediments (Rhoads, 1974) would result in more rapid oxygen depletion than in fine sediments. Increased bacterial action at high temperature may also be a contributing factor. Once anoxic conditions in the sediment become established, bacterial break-down of organic material may lead to formation of sulfides and $H_2S$, which are often highly toxic to organisms (Theede et al., 1969). In the summer burial experiments, the presence of sulfides was qualitatively noted, especially in the fine sediment treatments after 72 hrs. It is probable, therefore, that the synergistic effect on mortality observed was due to increased toxic sulfide production in the fine sediment treatments together with the decreased oxygen availability of these sediments.

Mauer et al. (1978, 1981a, 1981b, 1982) examined the responses to burial of several burrowing polychaetes as well as several species of bivalves and crustaceans. They found that that temperature did not have a clear effect on mortality, but rather influenced the percentage of animals which migrated upward through the sediment. Upward migration through sediment overburden appears to reduce mortality for many of organisms tested which have been tested (Mauer et al., 1978, 1981a, 1981b, 1982; Chang & Levings, 1978). Since Phragmatopoma lapidosa is a sessile tube dweller, it will be unable to migrate upward through the sediment.

Taylor & Littler (1982) have reported on the tolerance to burial of a congener of Phragmatopoma lapidosa, Phragmatopoma californica. They found that burial for 5 days in the laboratory at 16° C resulted in mortality in excess of 95%. Field studies of P. californica in a sand-influenced, rocky intertidal area indicated decreases in worm cover which resulted from sand burial. Taylor &

Littler (1982) concluded that P. californica is relatively intolerant of burial as compared with such species as the anemone Anthopleura elegantissima which can survive burial for up to three months.

Siltation Experiment

High concentrations of silt in the water column resulting from dredging, beach nourishment or even natural storm run off events can negatively affect aquatic organisms. These effects may be either sub-lethal (O'Conner et al., 1977; Sherk et al., 1976) or lethal (O'Conner et al., 1976). Sessile organisms may be particularly sensitive to silt in the water because of their inability to move elsewhere to avoid it. Corals, for example, have been shown to be sensitve to the presence of silt resulting from dredging (Hudson, 1981; Bak, 1978) and beach nourishment (Wershoven & Wershoven, 1984). Phragmatopoma lapidosa, however, showed no indication of a negative response over a four day period of exposure to extremely high silt levels. Experimental turbidities were 2 orders of magnitude greater than maximum levels reported from surf zones from either the west or east coast of Florida (Pinellas County, 31 JTU, Saloman & Naughton, 1979; Sebastian Inlet beach, 50 NTU, D. K. Stauble, Dept. of Oceanography & Ocean Engineering, Florida Institute of Technology, unpub. data). Silt loads were comparable to that measured in the immediate vicinity of a dredge discharge or that of a flood-stage river (O'Conner et al., 1976). The presence of high silt loads in the water column do not appear detrimental to P. lapidosa adults as long as the silt does not bury the worms. In high energy beach situations, silt tends to be rapidly removed from the beach nourishment sand and dispersed in the long-shore drift system (Stauble et al., 1983). Should physical conditions not disperse the silt from the near-shore zone, burial of worm reef and subsequent mortality, as indicated by the results of the burial experiments, might follow. This condition was observed following beach nourishment in the Pompano Beach - Lauderdale-by-the-Sea area with resultant damage to coral (Wershoven & Wershoven, 1984). Despite the apparent tolerance of adults to high silt loads, the tolerance of larval stages or newly settled individuals to this stress remains unknown.

Sulfide Toxicity Experiments

The presence of sulfides and $H_2S$ are generally correlated with a lack of oxygen and often occur in poorly oxygenated, muddy substrates. Theede et al. (1969) have shown that tolerance to sulfides is correlated with tolerance to low oxygen conditions and that species from mud bottom substrates are generally more tolerant than those from hard or sandy bottoms. Given this relation, it would be expected that P. lapidosa, which occurs in well oxygenated areas might be relatively intolerant of the presence of sulfides. At the highest sulfide concentration in oxygen deficient seawater (4.2 mg/l), 50% mortality of P. lapidosa occurred at between 24 and 48 hrs. Only 3 of 14 species, all of them crustaceans, tested by Theede et al. (1969) possessed a lower tolerance than P. lapidosa, suggesting that indeed it may be relatively sensitive to sulfides.

Mortality of P. lapidosa in the high sulfide concentration treatment with oxygenated water after 48 hrs was significantly less than for the same treatment of sulfide in deoxygenated water. This is because the presence of oxygen immediately began to decrease the concentration of sulfide, which was confirmed by the measurement after 24 hrs of sulfide concentrations in these treatments. Mortality in the oxygenated, high sulfide treatment (AS4) after 24 hrs was about 20%, while sulfide concentration had dropped from 4.25 to 0.8 mg/l.

Interpretation of this sulfide exposure experiment is complicated by the fact that sulfide production occurred in the jars of all treatments during the experiment. This can be seen as early as the 24 hour sample where decomposition rate calculations (see below) would predict only 0.016 mg/l $H_2S$ given the initial concentration for treatment AS4, while a mean of 0.82 mg/l was actually found. Part of this difference may be the slightly lower temperature of the experiment (23° C) versus that for the rate constant (25° C) determination, but sulfide production was clearly seen in all treatments at 48 hrs. At that time, observed sulfide levels were no longer related to initial treatment concentrations. It is certainly clear that from measured sulfide levels, treatment NS4 experienced the highest level of exposure for at least the first 24 hrs, and it was indeed this treatment which experienced the greatest mortality after 48 hrs. Other treatments which became exposed to sulfide only after 24 hrs (the controls: C, N) certainly had a lower total duration of exposure.

Extrapolating the results of the laboratory sulfide experiments to a field situation where beach nourishment is taking place is difficult. That sulfides can be present during such projects is indicated by a report from a beach nourishment project in North Carolina where estuarine sediments were dredged and placed on the beach (Reilly & Bellis, 1979, 1983) and $H_2S$ was qualitatively detected. Theede et al. (1969) suggest values up to 6-7 mg/l of sulfides may not be uncommon for mud bottoms. However, in the presence of oxygen, sulfide oxidises to sulphate if oxygen concentration is high, or first produces intermediate compounds such as sulphur, sulphite, thiosulphate and tetrathionate if oxygen concentration is relatively low (Richards, 1965). In the near shore habitats of P. lapidosa the seawater should be saturated with oxygen. At 25° C in oxygen-saturated seawater, approximately 1 mg/l of $H_2S$ takes 30 hours for complete oxidation of sulfides (Richards, 1965). At lower oxygen concentrations, the reaction is slowed considerably, with only half of the sulfides being oxidised in 60 hours. Low temperatures also considerably slow the reaction, with the reaction at 6.5° C being 4 times slower than at 25° C.

Use of the rate constant given by Richards (1965) allows calculation of the half life of sulfides by the formula

$$k = .693 / t_{.5} \qquad (1)$$

where k is the rate constant equal to 0.23/hr at 25° C and $t_{.5}$ is the half-life. With the half-life, it is possible to estimate the quantity of $H_2S$ at any time given some initial concentration of

$H_2S$ using the formula

(2) $$q_t = q_0\ (.5)^{t/t_{.5}}$$

where $q_t$ is the quantity of $H_2S$ at time t and $q_0$ is the initial concentration of $H_2S$. Assuming water with $H_2S$ at 6 mg/l entered the surf zone and was uniformly mixed with water saturated with oxygen at 25° C, the concentration of $H_2S$ at 12 hours would be only 0.38 mg/l. It would fall to only 0.02 mg/l at 24 hours, and would be essentially 0 by 48 hours. This suggests that for a single event introducing $H_2S$ into its environment, if P. lapidosa can survive exposure to $H_2S$ for 24 hours, then minimal damage should subsequently occur. The results of the sulfide exposure experiments after 24 hrs suggest no significantly increased mortality to P. lapidosa occurred in this time frame.

Decreased temperature would decrease the decomposition rate of sulfides. Using the rate constant given by Richards (1965) for 6.5° C., an initial concentration of 6 mg/l would leave 2.8, 1.3, and 0.28 mg/l at 12, 24 and 48 hours, respectively. This could potentially increase the mortality of P. lapidosa, although the role of temperature in influencing mortality in response to sulfide exposures is not completely known. Theede et al. (1969) found that isolated invertebrate tissue survived combined sulfide exposure and oxygen deficiency better at colder temperatures.

## Sediment Analysis

The sedimentary characteristics of worm tubes of the family Sabellariidae have been previously examined for Sabellaria vulgaris by Rees (1976), for Phragmatopoma californica by Scholl (1958), and for Phragmatopoma lapidosa by Kirtley (1966), Multer & Milliman (1967), and Gram (1968). Sedimentary analyses in the present study generally confirm the conclusions of these previous studies. P. lapidosa tends to remove the relatively finer sands from the beach sediments as indicated by Multer & Milliman (1967) and Gram (1968). In all samples except that from the Jupiter Inlet area, concentration of sediments smaller than 0.0625 mm was indicated. The Jupiter Inlet beach had the finest sediments of all sites sampled. However, for the entire sediment distribution, mean grain size for worm reef was greater than that for beach sand at three locations and less than that for beach sand at three locations. This pattern reflects the tendency of P. lapidosa to utilize a limited size range of sand grains for its tubes. Multer & Milliman (1967) found this size range to be mainly between 0.5 and 0.125 mm, which was confirmed in the present broader survey of sites in southeast Florida. Multer & Milliman (1967) suggest the concentration of particles smaller than 0.0625 mm is due to the use of these particles as mortar between larger sand grains. The present study also found that worms tend to concentrate $CaCO_3$ in the form of shell fragments in their tubes as was found by Multer & Milliman (1967) and Gram (1968).

The suggestion of Gram (1968) that removal of finer sediments by P. lapidosa results in an improved sorting of beach sediments is not supported by the present data. Of seven sample occasions, beach sediment was better sorted in 3 cases, less well sorted in 3 cases, and equal in sorting in one case. Examination of the data of Multer & Milliman (1967) also fails to support Gram's proposal as a general case.

Life History

Field studies of the sabellariid Phragmatopoma californica (Taylor & Littler, 1982; Littler et al., 1983) have suggested that this species has an opportunistic life history strategy. This conclusion is based on the continuous occurrence of viable gametes and the continuous presence of larvae in the plankton which allow it to rapidly colonize space made available by unpredictable disturbances. In contrast to many opportunistic species, P. californica can resist invasion by other species and persist in areas of low disturbance. In areas receiving periodic stress (sand-burial), P. californica can establish colonies, but mortality from the stress prevents persistence of the colonies.

Ecklebarger (1976) has shown that P. lapidosa also carry sex products during all months of the year, although actual presence of larvae in the plankton and larval settlement occurred in only a few months of the year. Ecklebarger (1976) concluded that spawning could be a year-round event. Larval developmental characteristics of P. lapidosa are very similar to those of P. californica (Ecklebarger, 1977). Ecklebarger (1976) also notes the susceptibility of P. lapidosa colonies to temperature stress which resulted in a die-off of intertidal colonies in the Seminole Shores, Florida area. Observation of P. lapidosa colonies in inshore areas near Ocean Ridge, Florida found the worm colonies to be patchily distributed, with an average life span of three months, due to sand movement (T. J. Campbell, A. V. Strock & Assoc., pers. comm.).

The similarities between P. californica and P. lapidosa are suggestive that the later species may also be a basically opportunistic species which can persist for considerable periods in benign habitats but which may be frequently removed in more physically variable areas by natural causes, particularly temperature stress and burial by sand.

# SUMMARY

The results of experiments designed to test the tolerance of Phragmatopoma lapidosa to stresses which might result from beach nourishment are summarized below.

1) Phragmatopoma lapidosa appears tolerant of very high silt loads and can tolerate silt levels 100 times natural levels for at least four days without increased mortality.

2) Phragmatopoma lapidosa can tolerate burial by sediment for only 24 hrs at summer temperatures. This species may tolerate burial for at least 72 hrs at cooler winter temperatures.

3) Burial with finer sediments results in significantly increased mortality as compared with coarser sediments, presumably due to the decreased porosity of the fine sediments which limits oxygen transport through pore water.

4) Phragmatopoma lapidosa does not appear particularly well adapted to surviving burial, but may instead use an opportunistic larval strategy which allows recolonization of areas which have been buried and re-exposed.

5) Phragmatopoma lapidosa appears able to tolerate exposure to sulfides for 24 hrs at levels likely to be released in a single exposure event. Repeated exposure which results in continuous exposure to sulfides at levels in the mg/l range may result in considerable mortality.

6) Phragmatopoma lapidosa does not appear particularly sensitive to the grain size composition of beach sediments since it occurs adjacent to beaches with a wide range of mean grain sizes. The worm's ability to select the grain sizes which it requires, primarily in the range 0.5 - 0.125 mm, which is a range present on most beaches, would allow it to occur in most sandy areas where hard substrate for attachment also occurs.

## RECOMMENDATIONS

1) Use of reducing sediments containing $H_2S$ as beach fill material should be avoided. Oxidation of sulfides is rapid in oxygenated water, but continuous sediment pumping operations might result in exposure to sulfides beyond the tolerance of the animals.

2) Fill placement would be preferable during cool water periods because of the increased period of time that burial could be survived.

3) The presence of fine sediments in beach fill which may result in siltation does not appear to be of major concern with regard to Phragmatopoma lapidosa, as long as the silt does not completely bury the organisms. It should be recognised that other organisms associated with beach rock outcrops whose tolerances have not been determined may be less tolerant of suspended silt.

4) In areas slated for beach nourishment, mapping of intertidal and subtidal rock outcrops and estimation of percent coverage of Phragmatopoma lapidosa should be carried out prior to beach nourishment. Presence of beach rock or other hard substrate is necessary for establishment of worm colonies, but is not evidence that worm colonies are indeed present. Given the probable life history pattern of P. lapidosa, most colonies may be ephemeral, and the presence of significant coverage should be verified before nourishment projects are redesigned or denied because of specific concerns over worm reef. In many cases, the outcroppings which are close inshore may be frequently buried by sand naturally and may support only temporary communities of organisms.

5) While it appears that Phragmatopoma lapidosa adults may be able to tolerate to a degree some of the stresses associated with beach nourishment, additional information on the species would be highly beneficial. Confirmation of the presumed opportunistic strategy of P. lapidosa is needed. More extensive observations of the seasonality of larval presence in the plankton and of larval settlement are desirable. Evaluation of the tolerances of larvae and newly settled individuals to beach nourishment stresses would allow determination of whether effects on larvae present a potential problem.

6) It must be remembered that although Phragmatopoma lapidosa may tolerate the stresses of beach nourishment to some degree, the diverse group of organisms associated with worm reef may be more sensitive. No data for the tolerances of these associated organisms is now available. Also, even where Phragmatopoma lapidosa is absent, there is often an extensive hard bottom community whose composition, ecology, and tolerance to stress is

virtually unknown. A cautious approach is advisable until these data gaps are filled.

## REFERENCES


Bak, R. P. M. 1978. Lethal and sublethal effects of dredging on reef corals. Mar. Poll. Bull. 9:14-16.

Chang, B. D. & C. D. Levings. 1978. Effects of burial on the heart cockle *Clinocardium nuttallii* and the Dungeness crab *Cancer magister*. Estuar. Coast. Mar. Sci. 7:409-412.

Clark, K.B. 1978. Summary of monitoring of seagrasses and sabellarid worm-reefs at Sebastian Inlet Florida. II. Post dredging report. Unpublished report to the Sebastian Inlet Tax District Commission.

Eckelbarger, K.J. 1976. Larval development and population aspects of the reef-building polychaete *Phragmatopoma lapidosa* from the east coast of Florida. Bull. Mar. Sci. 26:117-132.

Eckelbarger, K.J. 1977. Larval development of *Sabellaria floridensis* from Florida and *Phragmatopoma californica* from southern California (Polychaeta:Sabellariidae), with a key to the sabellariid larvae of Florida, and a review of development in the family. Bull. Mar. Sci. 27:241-255.

Eckelbarger, K.J. 1978. Metamorphosis and settlement in the Sabellariidae. In: Chia, F. and Rice, M. eds., *Settlement and Metamorphosis of Marine Larvae*, pp. 145-164. Elsevier, New York.

Gore, R.H., L.E. Scotto & L. J. Becker. 1978. Community composition, stability, and trophic partitioning in decapod crustaceans inhabiting some subtropical sabellariid worm reefs. Bull. Mar. Sci. 28:221-248.

Gram, R. 1968. A Florida sabellariid reef and its effect on sedimentary distribution. J. Sed. Petr. 38:863-868.

Hudson, J. H. 1981. Growth rates in *Montastraea annularis*: a record of environmental change in Key Largo Coral Reef Sanctuary, Florida. Bull. Mar. Sci. 31:444-459.

Inman, D. L. 1952. Measures for describing the size distribution of sediments. J. Sed. Petr. 22:125-145.

Kavanaugh, B. A. 1779. The effects of cadmium on the reef-forming sabellariid polychaete *Phragmatopoma lapidosa*. M. S. thesis, Florida Institute of Technology, Melbourne, Fl. pp 51.

Kirtley, D.W. 1966. Intertidal reefs of sabellariidae (Annelida, Polychaeta) along the coast of Florida. Masters thesis. Florida State University, Tallahassee.

Kirtley, D. W. 1967. Worm reefs as related to beach stabilization. Shore and Beach 35:31-34.

Kirtley. D.W. 1968. The reef builders. Natural History. 77:40-55.

Kirtley, D.W. 1974. Geological Society of America annual meeting, Miami Beach, Floirda, November 18-20, 1974. Unpublished field guide.

Kirtley, D.W. and W. F. Tanner. 1968. Sabellariid worms: builders of a major reef type. J. Sed. Petr. 38:73-78.

Kreuger, P.J. 1974. Transplantation and settling studies concerning the sabellariid Phragmatopoma lapidosa onto artificial concrete substrates. Masters thesis. Florida Institute of Technology, Melbourne Fl. pp. 72.

Littler, M. M., D. R. Martz & D. S. Littler. 1983. Effects of recurrent sand deposition on rocky intertidal organisms: importance of substrate heterogeneity in a fluctuating environment. Mar. Ecol. Prog. Ser. 11:129-139.

Mauro, N.A. 1975. The premetamorphic development rate of Phragmatopoma lapidosa Kinberg, 1867, compared with that in temperate sabellariids (Polychaeta:Sabellariidae). Bull. Mar. Sci. 25:387-392.

Maurer, D. R. T. Keck, J. C. Tinsman, W. A. Leathem, C. A. Wethe, M. Huntzinger, C. Lord & T. M. Church. 1978. Vertical migration of benthos in simulated dredged material overburdens. Vol. 1. Marine benthos. U. S. Army Engineers Waterways Experimental Station, Tech. Rept. D-78-35, I-97.

Maurer, D. R., T. Keck, J. C. Tinsman & W. A. Leathem. 1981a. Vertical migration and mortality of benthos in dredged material - part I: mollusca. Mar. Env. Res. 4:299-319.

Maurer, D. R., T. Keck, J. C. Tinsman & W. A. Leathem. 1981b. Vertical migration and mortality of benthos in dredged material - part II: crustacea. Mar. Env. Res. 5:301-317.

Maurer, D. R., T. Keck, J. C. Tinsman & W. A. Leathem. 1982. Vertical migration and mortality of benthos in dredged material - part III: polychaeta. Mar. Env. Res. 6:49-68.

Mehta, A.J. 1973. Coastal engineering study of sabellariid reefs: Report of hydraulic model study to the Harbor Branch Foundation Laboratory, Ft. Pierce, Fl. Gainesville, Coastal and Oceanographic Engineering Lab, Eng. and Indust. Exper. Sta., Univ. Florida. 67p.

Mulhern, E. 1976. A toxicity study of three refined fuel oils and a reference toxicant with respect to the sabellariid worm Phramatopoma lapidosa. Masters thesis. Florida Institute of Technology, Melbourne, Fl. pp. 45.

Multer, H. G. & T. D. Milliman. 1967. Geologic aspects of sabellariid reefs in southeastern Florida. Bull. Mar. Sci. 17:257-267.

O'Conner, J. M., D. A. Neumann & J. A. Sherk, Jr. 1976. Lethal effects of suspended sediments on estuarine fish. U. S. Army Corps of Engineers, Coastal Engineering Research Center, Tech. Pap. 76-20.

O'Conner, J. M., D. A. Newmann & J. A. Sherk, Jr. 1977. Sublethal effects of suspended sediments on estuarine fish. U. S. Army Corps of Engineers, Coastal Engineering Research Center, Tech. Pap. 77-3.

Puri, H. S. & N. O. Vernon. 1964. Summary of the geology of Florida and a guidebook to the classic exposures. Special Publ. #5. Florida Geol. Survey. pp. 312.

Rees, C. P. 1976. Sand grain size distribution in tubes of Sabellaria vulgaris Verill. Chesapeake Sci. 17:59-61.

Rhoads, D. C. 1974. Organism-sediment relations on the muddy sea floor. In: H. Barnes, ed. Oceanography and Marine Biology: an Annual Review. Vol. 12, pp. 263-300. London, Allen & Unwin.

Reilly, F. J., Jr. & V. J. Bellis. 1978. A study of the ecological impact of beach noursihment with dredged materials on the intertidal zone. East Carolina Univ. Inst. for Coast. & Mar. Resources Tech. Rept. No. 4. pp. 107.

Reilly, F. J., Jr. & V. J. Bellis. 1983. The ecological impact of beach nourishment with dredged materials on the intertidal zone at Bogue Banks, North Carolina. U. S. Army Corps of Engineers, Coastal Engineering Research Center, Misc. Rept. 83-3.

Richards, F. A. 1965. Anoxic basins and fjords. In:Riley , J. P. & G. Skirrow, eds. Chemical Oceanography. Vol. 1. Academic Press, New York. pp. 712.

Riley , J. P. & G. Skirrow, eds. 1965. Chemical oceanography. Vol. 1. Academic Press, New York. pp. 712.

Saloman, C. H. & S. P. Naughton. 1979. Fishes of the littoral zone, Pinellas County, Florida. Florida Sci. 42:85-93.

Scholl, D. W. 1958. Effects of an arenaceous tube-building polychaete upon the sorting of a beach sand at Abalone Cove, California. Compass Magazine, 35:276-283.

Sherk, J. A., Jr., J. M. O'Conner & D. A. Neumann. 1976. Effects of suspended solids on selected estuarine plankton. U. S. Army Corps of Engineers, Coastal Engineering Research Center, Misc. Rept. 76-1.

Sokal, R. R. & F. J. Rohlf. 1981. Biometry. W. H. Freeman, San Francisco, pp. 859.

Stauble, D. K., M. E. Hansen, R. L. Hushla & L. E. Parson. 1983. Biological and physical monitoring of beach erosion control project, Indialantic/Melbourne Beach, Florida. Part I: Physical monitoring. Unpublished report to the U. S. Army Corps of Engineers, Jacksonville District.

Taylor, P. R. & M. M. Littler. 1982. The roles of compensatory mortality, physical disturbance, and substrate retention in the development and organization of a sand-influenced, rocky intertidal community. Ecology 63:135-146.

Theede, H., A. Ponat, K. Hiroki & C. Schlieper. 1969. Studies on the resistance of marine bottom invertebrates to oxygen-deficiency and hydrogen sulfide. Mar. Biol. 2:325-337.

Van Montfrans, J. 1981. Decapod crustaceans associated with worm rock (Phramatopoma lapidosa Kinberg) in southeastern Florida. Masters thesis. Florida Atlantic University, Boca Raton, Fl. pp. 290.

Vernberg, W. B. & F. J. Vernberg. 1972. Environmental Physiology of Marine Animals. Springer-Verlag, New York, pp. 346.

Wershoven, R. & Wershoven, J. 1984. Pompano Beach - Lauderdale-by-the Sea beach nourishment project and its effects on the coral reefs. Unpublished rept. to the Broward County Environmental Quality Control Board.